Chapter A5: Methods Used to Evaluate I&E

This chapter describes the methods EPA used to evaluate impingement and entrainment (I&E) at the case study facilities, including methods used to forecast the consequences of I&E losses of early life stages for the adult population, fishery harvests, and population biomass production. Section A5-1 outlines the overall approach, Section A5-2 describes the source data, Section A5-3 presents details of the biological models used, and Section A5-4 discusses uncertainties in the analyses. Chapters A9 (benefits transfer), A10 (Random Utility Model), and A11 (Habitat-based Replacement Cost) discuss how these loss estimates are valued for the case study benefits analyses.

CHAPTER CONTENTS

A5-1 Overview of Procedure for Evaluating I&E

The same general procedure for evaluating I&E records was followed for each facility, but with appropriate facility-specific considerations pertaining to data availability and identification of predominant species composition. The basic approach estimated losses to fishery resources resulting from species-specific and life-stage-specific I&E. Losses were expressed as (1) foregone age 1 equivalents, (2) foregone fishery yields, and (3) foregone biomass production using common fishery modeling techniques (Ricker, 1975; Hilborn and Walters, 1992; Quinn and Deriso, 1999). These foregone resources were modeled using facility-specific I&E rates combined with relevant species life history characteristics such as growth rates, natural mortality rates, and fishing mortality rates.

A5-2 Source Data

A5-2.1 Facility I&E Monitoring

The inputs for EPA's analyses included the empirical I&E counts reported by each facility. The general approach to I&E monitoring was similar at most case study facilities. Impingement monitoring involved sampling impingement screens or catchment areas, counting the impinged fish, and extrapolating the count to an annual basis. Entrainment monitoring typically involved intercepting a small portion of the intake flow at a selected location in the facility, collecting fish by sieving the water sample through nets or other collection devices, counting the collected fish, and extrapolating the counts to an annual basis. EPA used life stage-specific annual losses for assessment of entrainment losses and assumed that all fish killed by impingement were age 1 at the time of death. Although these general sampling procedures were followed by most facilities, specific methods of collecting and reporting I&E data, and the complexity and time span of analysis, differed substantially among case study facilities. To the extent possible, EPA considered and evaluated facility-specific monitoring and reporting procedures, as described in EPA's individual case study reports.

A5-2.2 Species Evaluated

EPA conducted detailed species-specific loss analyses for species that were most predominant in facility collections or had special significance (e.g., threatened or endangered status). I&E was analyzed in terms of losses to the commercial or recreational fishery (for those species that are fished), or as loss of the forage prey base (for those species that are not fished). A small fraction of species that were identified in I&E records were not evaluated on a species-specific basis by EPA because of a lack of life history information. These species were treated as an aggregate, and their I&E rates were expressed as a fraction of the total I&E.

A5-2.3 Life History Data

The life history data used in EPA's case studies usually included species-specific growth rates, the fraction of each age class vulnerable to harvest, fishing mortality rates, and natural (nonfishing) mortality rates. Each of these parameters was also stage-specific, with the exception of mortality rates which are typically constant for fish older than a given catchability threshold.

EPA obtained life history data from facility reports, the fisheries literature, and publicly available fisheries databases (e.g., FishBase). To the extent feasible, EPA used species-specific and region-specific life history data most relevant to local populations near the case study facility. Detailed citations are provided in life history tables accompanying each case study report.

A static set of life history parameters was used for all data analyses. No stochastic or dynamic effects such as compensatory mortality or growth, or random environmental variation were used.
In cases where no information on survival rates was available for individual life stages, EPA deduced survival rates for an equilibrium population based on records of lifetime fecundity using the relationship presented in C.P. Goodyear (1978) and below in Equation (1):

$$S_{eq} = 2/fa \qquad \text{(Equation 1)}$$

where:

S_{eq} = the probability of survival from egg to the expected age of spawning females
fa = the expected lifetime total egg production

Published fishing mortality rates (F) were assumed to reflect combined mortality due to both commercial and recreational fishing. Basic fishery science relationships (Ricker, 1975) among mortality and survival rates were assumed, such as:

$$Z = M + F \qquad \text{(Equation 2)}$$

where:

Z = the total instantaneous mortality rate
M = natural (nonfishing) instantaneous mortality rate
F = fishing instantaneous mortality rate

and

$$S = e^{(-Z)} \qquad \text{(Equation 3)}$$

where:

S = the survival rate as a fraction

A5-3 Biological Models Used to Evaluate I&E

The methods used to express I&E losses in units suitable for economic valuation are outlined in Figure A5-1 and described in detail below.

A5-3.1 Modeling Age-1 Equivalents

The Equivalent Adult Model (EAM) is a method for expressing I&E losses as an equivalent number of individuals at some other life stage, referred to as the age of equivalency (Horst 1975a; C.P. Goodyear, 1978; Dixon, 1999). The age of equivalency can be any life stage of interest. The method provides a convenient means of converting losses of fish eggs and larvae into units of individual fish and provides a standard metric for comparing losses among species, years, and facilities. For the § 316(b) case studies, EPA expressed I&E losses as an equivalent number of age-1 individuals. This is the number of impinged and entrained individuals that would otherwise have survived to be age 1 plus the number of impinged individuals (which are assumed to be impinged at age 1).

The EAM calculation requires life-stage-specific entrainment counts and life-stage-specific mortality rates from the life stage of entrainment to the life stage of equivalence. The cumulative survival rate from age at entrainment until age 1 is the product of all stage-specific survival rates to age 1. The calculation is:

$$S_{j,1} = S_j^* \prod_{i=j+1}^{j_{\max}} S_i \qquad \text{(Equation 4)}$$

where:

$S_{j,1}$ = cumulative survival from stage j until age 1
S_j = survival fraction from stage j to stage $j + 1$
S^*_j = $2S_j e^{-\log(1+S_j)}$ = adjusted S_j
$j_{\max}$ = the stage immediately prior to age 1

Equation 4 defines $S_{j,1}$, which is the expected cumulative survival rate (as a fraction) from the stage at which entrainment occurs, j, through age 1. The components of Equation 4 represent survival rates during the different life stages between life stage j, when a fish is entrained, and age 1. Survival through the stage at which entrainment occurs, j, is treated as a special case because the amount of time spent in that stage before entrainment is unknown and therefore the known stage specific survival rate, S_j, does not apply because S_j describes the survival rate through the entire length of time that a fish is in stage j. Therefore, to find the expected survival rate from the day that a fish was entrained until the time that it would have passed into the subsequent stage, an adjustment to S_j is required. The adjusted rate S^*_j describes the effective survival rate for the group of fish entrained at stage j, considering the fact that the individual fish were entrained at various specific ages within stage j.

Age-1 equivalents are then calculated as:

$$AE1_{j,k} = L_{j,k} S_{j,1} \qquad \text{(Equation 5)}$$

where:

$AE1_{j,k}$ = the number of age-1 equivalents killed during life stage j in year k
$L_{j,k}$ = the number of individuals killed during life stage j in year k
$S_{j,1}$ = the cumulative survival rate for individuals passing from life stage j to age 1 (equation 4)

The total number of age-1 equivalents derived from losses at all stages in year *k* is then given by:

$$AE1_k = \sum_{j = j_{\min}}^{j_{\max}} AE1_{j,k} \qquad \text{(Equation 6)}$$

where:

$AE1_k$ = the total number of age-1 equivalents derived from losses at all stages in year *k*

These calculations were used to derive the total age-1 equivalents for each species and year of sampling at each case study facility.

A5-3.2 Modeling Foregone Fishery Yield

Foregone fishery yield is a measure of the amount of fish or shellfish (in pounds) that is not harvested because the fish are lost to I&E. EPA estimated foregone yield using the Thompson and Bell model (Ricker, 1975). The model provides a simple method for evaluating a cohort of fish that enters a fishery in terms of their fate as harvested or not-harvested individuals. The method is based on the same general principles that are used to estimate the expected yield in any harvested fish population (Hilborn and Walters, 1992; Quinn and Deriso, 1999).

The key parameters of the Thompson and Bell model are natural mortality rate (M), fishing mortality rate (F), and weight at age (in pounds) of harvested fish. The general procedure involves multiplying age-specific harvest rates by age-specific weights to calculate an age-specific expected yield (in pounds). The lifetime expected yield for a cohort of fish is then the sum of all age-specific expected yields, thus:

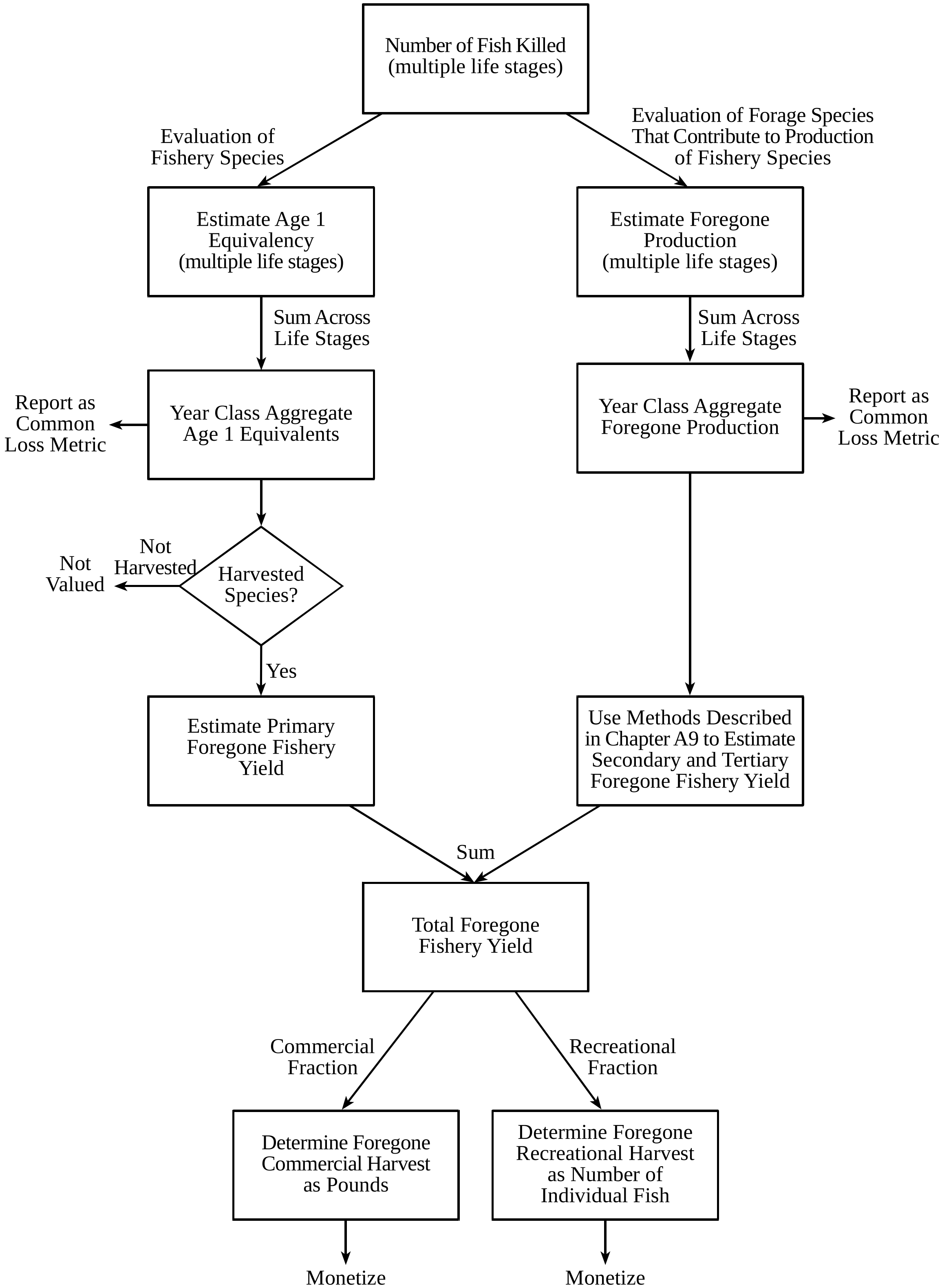
$$Y_k = \sum_j \sum_a L_{jk} S_{ja} W_a (F_a / Z_a) \qquad \text{(Equation 7)}$$

where:

Y_k = foregone yield (pounds) due to I&E losses in year *k*
L_{jk} = losses of individual fish of stage *j* in the year *k*
S_{ja} = cumulative survival fraction from stage *j* to age *a*
W_a = average weight (pounds) of fish at age *a*
F_a = instantaneous annual fishing mortality rate for fish of age *a*
Z_a = instantaneous annual total mortality rate for fish of age *a*

Figure A5-1 outlines the modeling of foregone fishery yield. EPA partitioned its estimates of total foregone yield for each species into two classes, foregone recreational yield and foregone commercial yield, based on the relative proportions of recreational and commercial state-wide aggregate catch rates of that species. Pounds of foregone yield to the recreational fishery were re-expressed as numbers of individual fish based on the expected weight of an individual harvestable fish. Chapter A9 describes the methods used to derive dollar values for foregone commercial and recreational yields for the case study benefits analyses.

Figure A5-1: General Approach Used to Evaluate I&E Losses as Foregone Fishery Yield



A5-3.3 Modeling Foregone Production

In addition to expressing I&E losses as lost age 1 equivalents (and subsequent lost yield, for harvested species), I&E losses were also expressed as foregone production. Foregone production is the expected total amount of future growth (expressed as pounds) of individuals that were impinged or entrained, had they not been impinged or entrained. The foregone production of forage species (those species not harvested for recreational or commercial fisheries) is used to estimate the subsequent reduction in harvested species yield that results from a decrease in the food supply (details provided in Section A5-3.4).[1] This indirect effect on harvested species yield can then be added to estimates of foregone yield that result from direct I&E losses of harvested species to provide an estimate of total foregone yield (Figure A5-1).

Production foregone is calculated by simultaneously considering the age-specific growth increments and survival probabilities of individuals lost to I&E, where production includes the biomass accumulated by individuals alive at the end of a time interval as well as the biomass of those individuals that died before the end of the time interval. Thus, the production foregone for a specified age or size class, *i*, is calculated as:

$$P_i = \frac{G_i N_i W_i (e^{(G_i - Z_i)} - 1)}{G_i - Z_i}$$ (Equation 8)

where:

P_i = expected production (pounds) for an individual during stage *i*
G_i = the instantaneous growth rate for individuals of stage *i*
N_i = the number of individuals of stage *i* lost to I&E (expressed as equivalent losses at subsequent ages)
W_i = average weight (in pounds) for individuals of stage *i*
Z_i = the instantaneous total mortality rate for individuals of stage *i*

P_j, the production foregone for all fish lost at stage *j*, is calculated as:

$$P_j = \sum_{i=j}^{t_{max}} P_{ji}$$ (Equation 9)

where:

P_j = the production foregone for all fish lost at stage *j*
t_{max} = oldest age group considered

P_T, the total production foregone for fish lost at all stages *j*, is calculated as:

[1] Foregone production of harvested species lost through I&E (i.e., the amount of future production of harvested fish species lost because of I&E) is also calculated in this process because it is necessary for the monetization of the indirect effects of a reduction in the food supply (see Section A3-4 for details).

$$P_T = \sum_{j=t_{min}}^{t_{max}} P_j \qquad \text{(Equation 10)}$$

where:

P_T = the total production foregone for fish lost at all stages j
t_{min} = youngest age group considered

A5-3.4 Evaluation of Forage Species Losses

Foregone production of forage species due to I&E losses may be considered a reduction in the aquatic food supply, and therefore a cause of reduced production of other species, including harvested species, at higher trophic levels. I&E losses of forage species have both immediate and future impacts because not only is existing biomass removed from the ecosystem, but also the biomass that would have been produced in the future is no longer available as food for predators (Rago, 1984; Summers, 1989). The Production Foregone Model accounts for these consequences of I&E losses by considering losses of both existing biomass and the biomass that would have been transferred to other trophic levels but for the removal of organisms by I&E (Rago, 1984; Dixon, 1999). Consideration of the future impacts of current losses is particularly important for fish, since there can be a substantial time between loss and replacement, depending on factors such as spawning frequency and growth rates (Rago, 1984).

EPA evaluated I&E losses of forage species (i.e., species that are not targets of recreational or commercial fisheries) using two general approaches. The first approach expressed losses as numbers of age 1 equivalents. These losses were valued based on hatchery replacement costs as described in Chapter A9. The second approach, referred to in this document as the "ecological approach," was developed by EPA to provide a way to value lost forage in terms of the reductions in losses of harvested species that result from loss of their prey base. In this case, the economic value of lost forage species is derived from the value of foregone production of harvested species as described in Chapter A9.

The ecological approach uses two distinct estimates of trophic transfer efficiency within two kinds of food web pathways to relate foregone forage production to foregone fishery yield. The two estimates, termed secondary and tertiary foregone yield, reflect (1) that portion of total forage production that has high trophic transfer efficiency because it is directly consumed by harvested species (secondary foregone yield), and (2) the remaining portion that has a low trophic transfer efficiency because it is not consumed directly by harvested species but instead reaches harvest species indirectly after passage through other parts of the food web (tertiary foregone yield). This is illustrated in Figure A5-2.

The basic assumption behind EPA's approach to evaluating losses of forage species is that a decrease in the production of forage species can be related to a decrease in the production of predator species through a factor related to trophic transfer efficiency. Thus, in general,

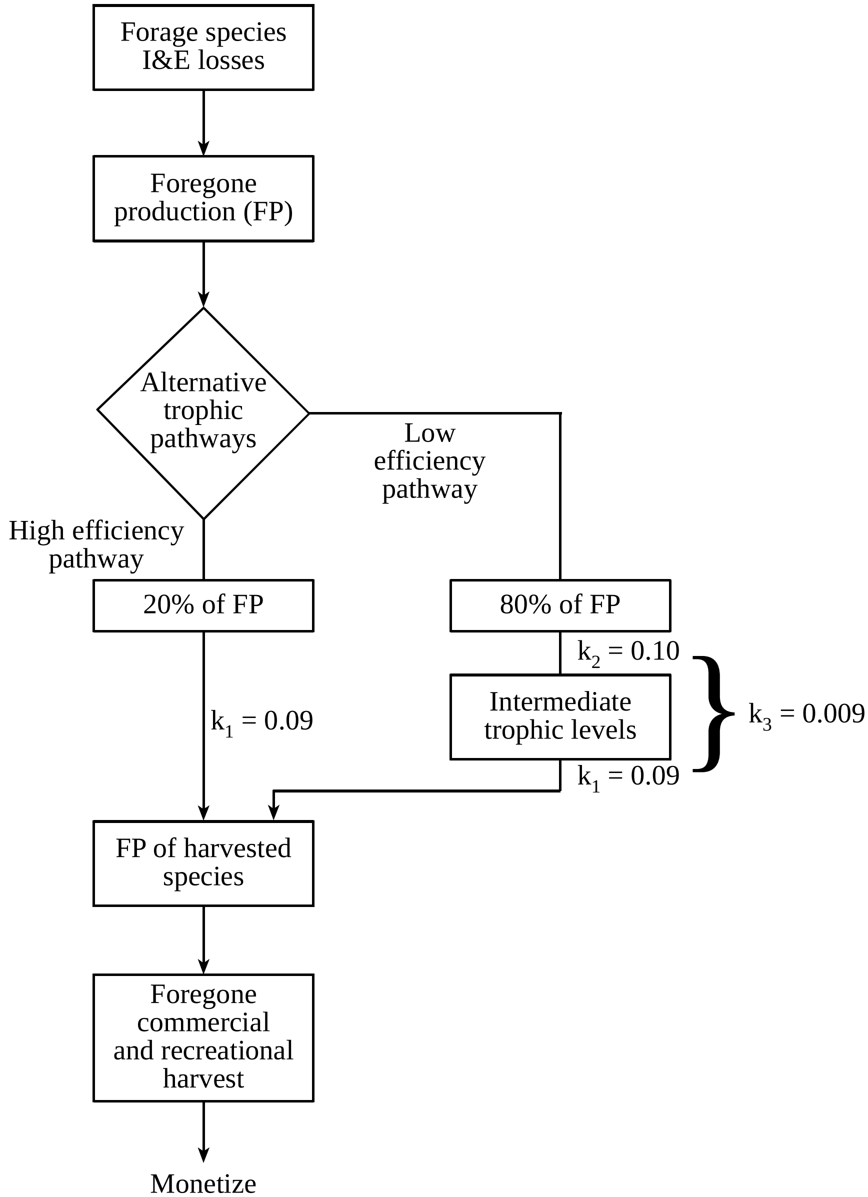
$$P_p = k\, P_f \qquad \text{(Equation 11)}$$

where:

P_p = the biomass production of a predator species (in pounds)
k = the trophic transfer efficiency (a scalar with magnitude typically about 0.10)
P_f = the biomass production of a forage species (in pounds)

Equation 11 is applicable to trophic transfer on a species-to-species basis where one species is strictly prey and the other species is strictly a predator. For the § 316b case studies, commercially or recreationally valuable fish were considered predators.

Figure A5-2: Trophic Transfer Model for Valuation of Foregone Biomass Production (FP) of Forage Species by Estimating Consequential Reductions in Commercial and Recreational Harvest



It is difficult to determine, on a community basis, an appropriate value of *k* that relates aggregate forage production and aggregate predator production, since the actual trophic pathways are complicated. Therefore, for the purposes of the benefits case studies, EPA assumed a general value of $k = 0.09$ for a direct prey-to-predator transfer, and assumed that 20 percent of forage production would be consumed directly by commercially or recreationally important predators. EPA also assumed that the remaining 80 percent of forage production would be consumed indirectly by commercially or recreationally important predators (via other intermediate predators), and that *k* for these trophic routes would be scaled by an additional factor of 0.1. Thus:

$$P_{2p} = 0.2\, k_1\, P_f \qquad \text{(Equation 12)}$$

and

$$P_{3p} = 0.8\, k_3\, P_f \qquad \text{(Equation 13)}$$

where:

P_f = aggregate of foregone production of all forage species lost to I&E
P_{2p} = secondary production of commercially or recreationally important predator species
P_{3p} = tertiary production of commercially or recreationally important predator species
k_1 = trophic transfer efficiency constant with value 0.09
k_3 = trophic transfer efficiency constant with value 0.009 = $k_1 k_2$

Foregone commercial and recreational fish production estimated by these two models is referred to here as secondary production and tertiary production, respectively. The associated foregone yield is referred to as secondary foregone yield and tertiary foregone yield. The net effect of this dual pathway model for trophic transfer is an assumed trophic transfer efficiency of 0.025, which is the weighted net transfer efficiency ($0.2k_1 + 0.8k_3$).

A5-4 UNCERTAINTY

The modeling methods used for the § 316(b) case studies, modeling assumptions, and results are presented in each case study report in a manner intended to provide the reader with a clear and complete understanding of how and why particular procedures were selected and executed. However, despite following sound scientific practice throughout, it is impossible to avoid numerous sources of uncertainty that may cause the reported results to be imprecise or to carry potential statistical bias. Uncertainty of this nature is not unique to EPA's studies of I&E effects (Finkel, 1990).

The case study analyses attempt to model a process that is enormously complex. The analyses are an interdisciplinary process that span several major fields of study, including aquatic and marine ecology, fishery science, estuarine hydrodynamics, economics, and engineering, each of which acknowledges its own complex suite of interacting factors. A formal quantification of variability and uncertainty (which could be accomplished by analytic means or by Monte Carlo methods) would require information about the variance associated with each part of this large set of factors, but much of that information is lacking. Nonetheless, because EPA took care to use the best biological models and data available for its I&E evaluations and economic analyses, EPA believes that the case study results provide a reliable, scientifically sound basis for estimating of the potential benefits of the proposed § 316(b) regulations. EPA notes that the models used are based on standard fisheries methods.

The following discussion outlines the major uncertainties in the case study analyses. Uncertainty may be classified into two general types (Finkel, 1990). One type, referred to as structural uncertainty, reflects the limits of the conceptual formulation of a model and relationships among model parameters. The other general type is parameter uncertainty, which flows from uncertainty about any and all of the specific numeric values of model parameters. The following discussion considers these two types of uncertainty in relation to the models used by EPA to evaluate I&E.

A5-4.1 Structural Uncertainty

The models used by EPA to assess the economic consequences of I&E simplify a very complex process. The degree of simplification is substantial but necessary because of the limited availability of empirical data. Table A5-1 provides examples of some potentially important considerations that are not captured by the models used in the case studies. EPA believes that these structural uncertainties will generally lead to inaccuracies, rather than imprecision, in the final results.

Table A5-1: Factors Affecting Model Uncertainty in EPA's Assessment of I&E Consequences

Type	General Treatment in Model	Specific Treatment in Model
Generally simple structure	Species lost to I&E treated independently	Fish species grouped into two categories: harvested (commercial, recreational, or both) or not harvested (forage)
Biological submodels	No dynamic elements	Life history parameters were static (i.e., growth and survival did not vary through time in response to long term trends in community); growth and survival rates in the subpopulation of fish that did not suffer I&E mortality did not change in response to possible compensatory effects
Economic submodels	No dynamic elements	Ratio of direct to indirect benefits was static through time; market values of harvested species were inelastic (i.e., were fixed and thus not responsive to market changes that may occur due to increased supply when yield is higher)
	Fish stock relevance	Fishable stock associated with I&E losses assumed to be within the state where facility is located
	Angler experience	I&E losses at a facility assumed to be relevant to angler experience (or perception) relevant to Random Utility Model (RUM) models of sport fishery economics.

A5-4.2 Parameter Uncertainty

The models used by EPA to evaluate I&E require knowledge of growth rates and mortality rates that are species-specific and often age-specific as well. Uncertainty about the values of these parameters arises for two general reasons. The first source of uncertainty is imperfect precision and accuracy of the original estimate because of unavoidable sampling and measurement errors. The second major source of uncertainty is the applicability of previous parameter estimates to the current situation. Although EPA used published parameter estimates that were judged to be most pertinent to the regions considered in the case studies, it is unlikely that growth and survival rates in case study areas would be exactly that same as survival rates developed in a different setting. The applicability of published parameter estimates may also vary through time because of changes in the local ecosystem as a whole, or because of climatological changes and other stochastic factors. All of these types of temporal changes could be manifest as significant temporary effects, or as persistent long-term trends.

Table A5-2 presents some examples of parameter uncertainty. In all these cases, increasing uncertainty about specific parameters implies increasing uncertainty about the reported point estimates of I&E losses. The point estimates are biased only insofar as the input parameters are biased in aggregate (i.e., inaccuracies in multiple parameter values that are above the "actual" values but below the "actual" values in other cases may tend to counteract). In this context, EPA believes that parameter uncertainty will generally lead to imprecision, rather than inaccuracies, in the final results.

Table A5-2: Parameters Included in EPA's I&E Assessment Model that Are Subject to Uncertainty

Type	Factors	Examples of Uncertainties in Model
Monitoring/loss rate estimates	Sampling regimes	Sampling regimes subject to numerous plant-specific difficulties; no established guidelines or performance standards for how to design and conduct sampling regimes
	Extrapolation assumptions	Extrapolation to annual I&E rates requires numerous assumptions required by monitoring designers and analysts regarding diurnal/seasonal/annual cycles in fish presence and vulnerability and various technical factors (e.g., net collection efficiency; hydrological factors affecting I&E rates)
	Species selection	Facilities responding to variable sets of regulatory demands; criteria for selection of species to evaluate not well-defined; flexible interpretation; variations in data availability in resulting time series
	Sensitivity of fish to I&E	Through-plant mortality assumed to be 100 percent; some back-calculations required in cases where facilities had reported only I&E rates that assumed <100 percent mortality
Biological/life history	Natural mortality rates	Used stage-specific natural mortality rates (M) for >10 stages per species
	Growth rates	Simple exponential growth rates or simple size-at-age parameters used
	Geographic considerations	Migration patterns; I&E occurring during spawning runs or larval out-migration? Location of harvestable adults; intermingling with other stocks
	Forage valuation	Harvested species assumed to be food limited; trophic transfer efficiency to harvested species estimated based on general models
Stock characteristics	Fishery yield	Used one species-specific value for fishing mortality rate (F) among all ages for any harvested species; used few age-specific constants for fraction vulnerable to fishery
	Harvest behavior	No assumed dynamics among harvesters to alter fishing rates or preferences in response to changes in stock size; recreational access assumed constant (no changes in angler preferences or effort)
	Stock interactions	I&E losses assumed to be part of reported fishery yield rates on a statewide basis; no consideration of possible substock harvest rates or interactions
	Compensatory growth	None
	Compensatory mortality	None
Ecological system	Fish community	Long-term trends in fish community composition or abundance not considered (general food webs assumed to be static); used simple three-compartment predation model and constant values for trophic transfer efficiency (specific trophic interactions not considered)
	Spawning dynamics	Sampled years assumed to be typical with respect to choice of spawning areas and timing of migrations that could affect vulnerability to I&E (e.g., presence of larvae in vicinity of CWIS)
	Hydrology	Sampled years assumed to be typical with respect to flow regimes and tidal cycles that could affect vulnerability to I&E (e.g., presence of larvae in vicinity of CWIS)
	Meteorology	Sampled years assumed to be typical with respect to vulnerability to I&E (e.g., presence of larvae in vicinity of CWIS)

A5-4.3 Uncertainties Related to Engineering

EPA's evaluation of I&E consequences was also affected by uncertainty about the engineering and operating characteristics of the case study facilities. It is unlikely that plant operating characteristics (e.g., seasonal, diurnal, or intermittent changes in intake water flow rates) were constant throughout any particular year, which therefore introduces the possibility of bias in the loss rates reported by the facilities. EPA assumed that the facilities' loss estimates were provided in good faith and did not include any intentional biases, omissions, or other kinds of misrepresentations.